Run II: The frontier ???

Difficult to review all in 30 minutes -->
not review

Outline

Introduction
Ingredients needed for physics
Jet final states
* to structure function
* jet algorithms
BFKL
W/Z + jets
Rapidity gaps
Luminosity
Wishlist + summary

The rest…..

Personal view not the D0 view !!

Within D0: “QCD label”.

As if something dirty !!!

QCD or our understanding of it, underlies every measurement at the Tevatron

Tevatron: a *qq, qg, gg* wide band machine. Similar to e^+e^- machine, but need QCD to get initial state right.

To do full program need:

$$$$+ people BIG

- excellent detectors……will have
- reliable theory predictions
- reliable simulations
- parton distributions = proton -> parton
- tools & algorithms

This workshop and especially the next few months

Crucial ingredients to physics success of Run I :

Tevatron machine
Detectors & collaborations (people)

but also

Simulations i.e. Pythia, Herwig, Isajet
Perturbative predictions (JETRAD, DYRAD, EKS etc..)
Parton distributions

MRS,
CTEQ

Other experiments
(now also Tevatron)

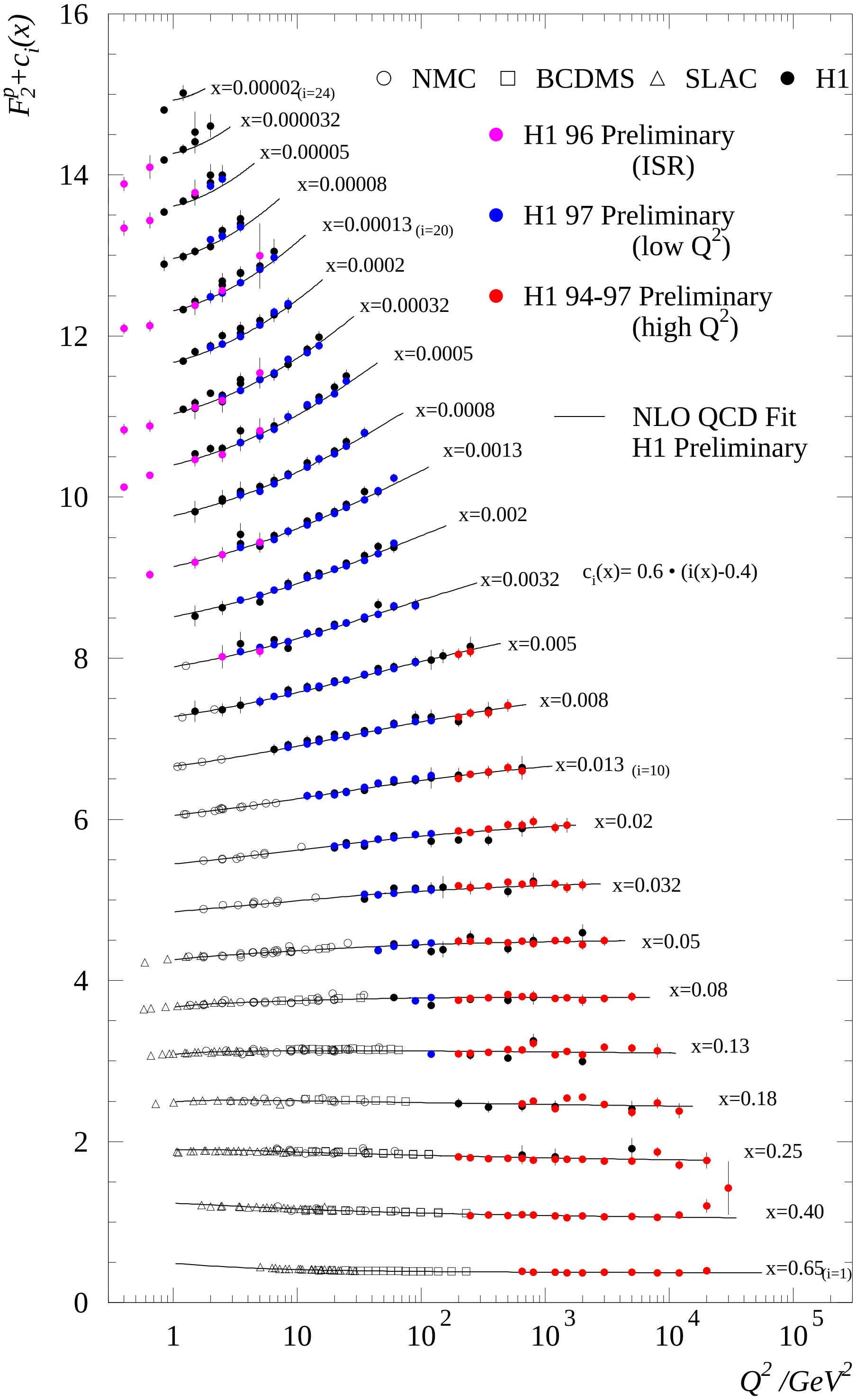
H1
ZEUS

Accuracy of data used in pdf determinations so accurate that controversial or data sets with theory uncertainties can be ignored !

Direct photon data not included:
(WA70,E706, CDF, D0)

Therefore they get all attention &
new additions to QCD

HERA now

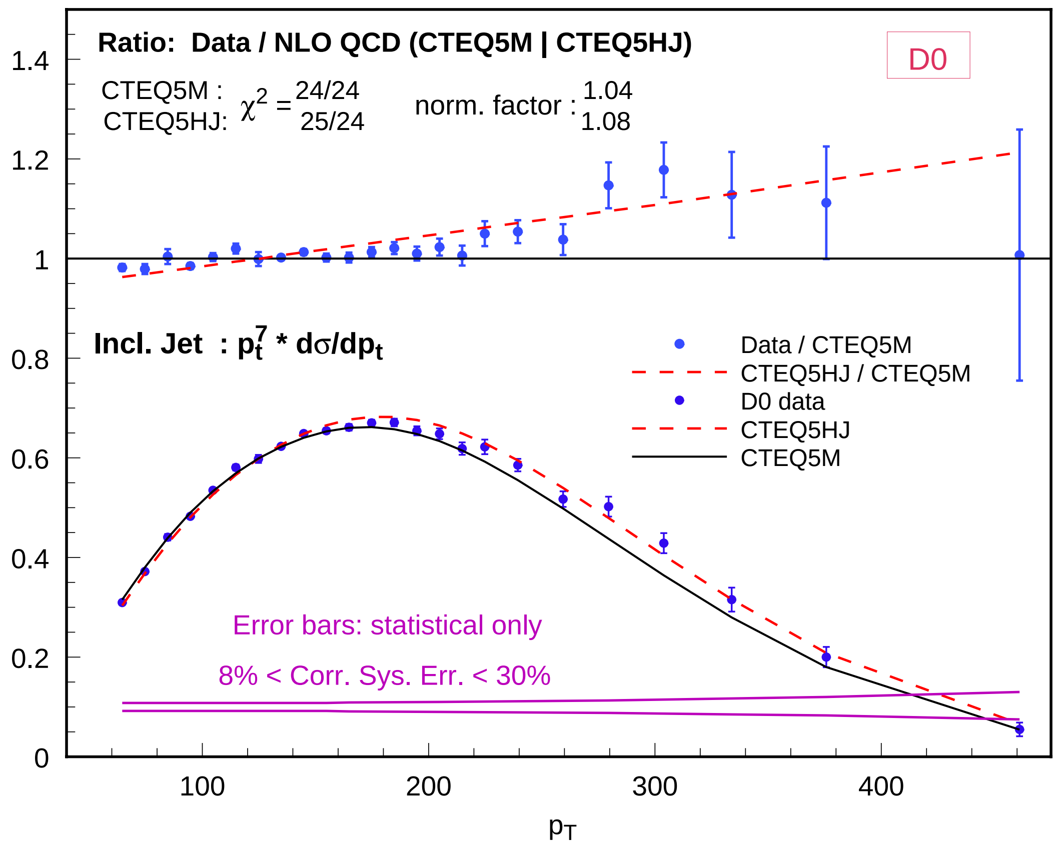


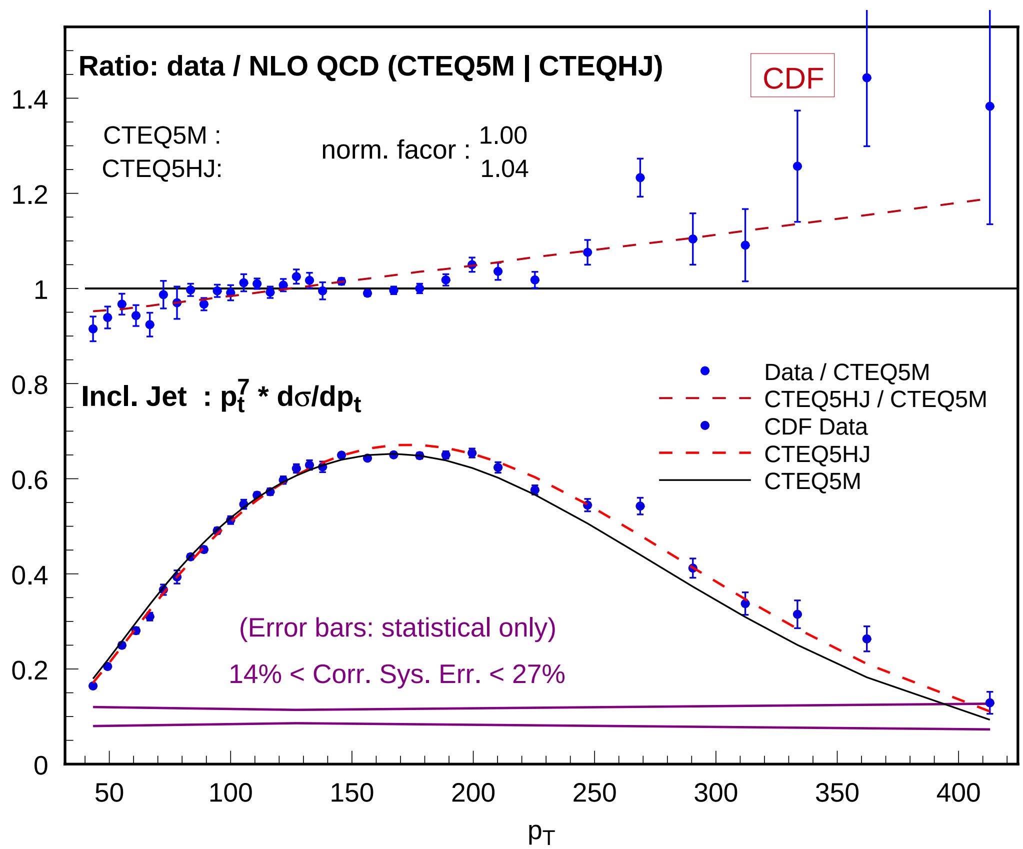
However ***REAL*** luminosity still to come !!

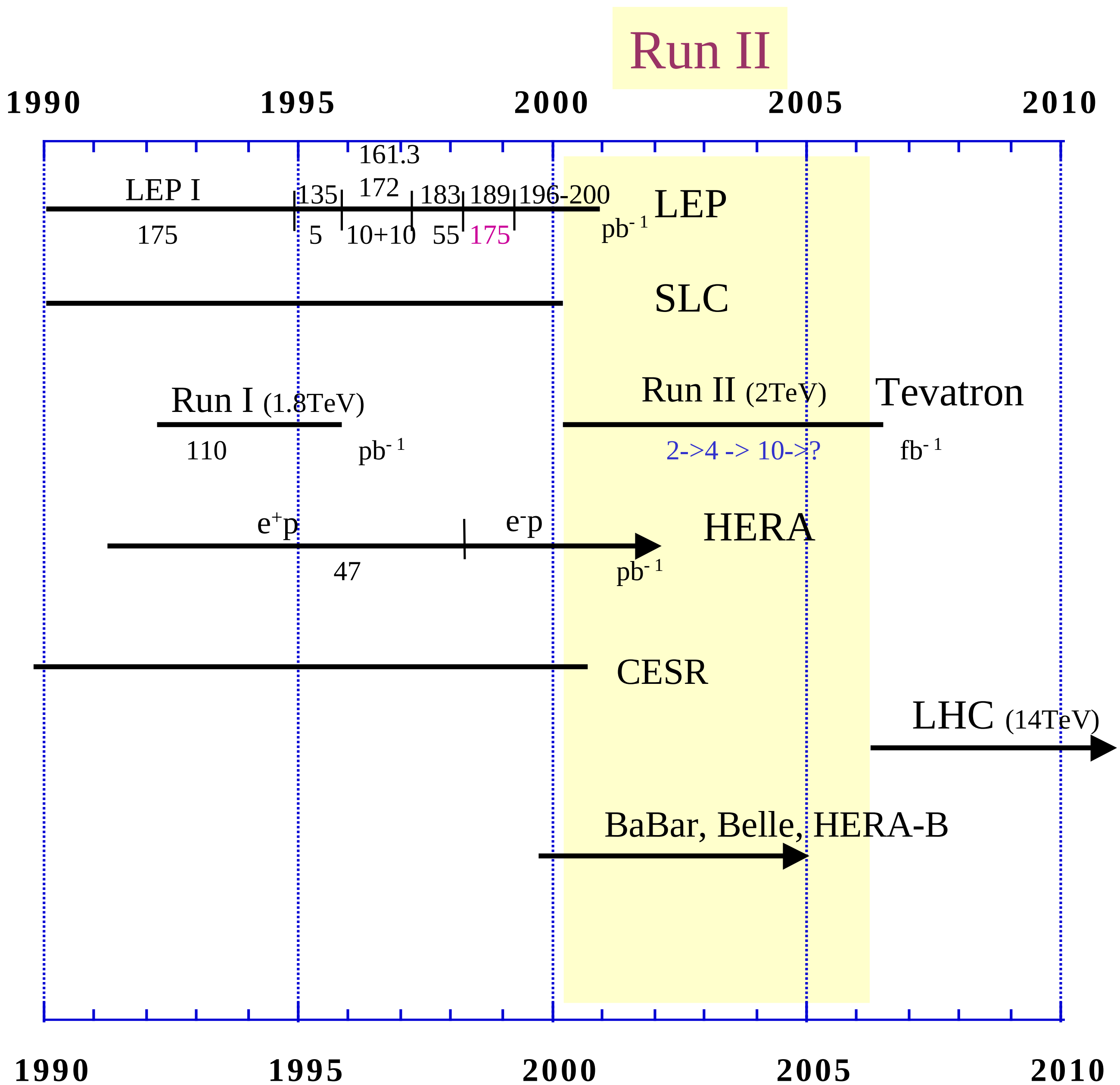
- Now running e$^-$
- Do charged current
- Valence quarks
- Gluons @ higher x

Unprecedented precision in next few years

Good for Run II & LHC

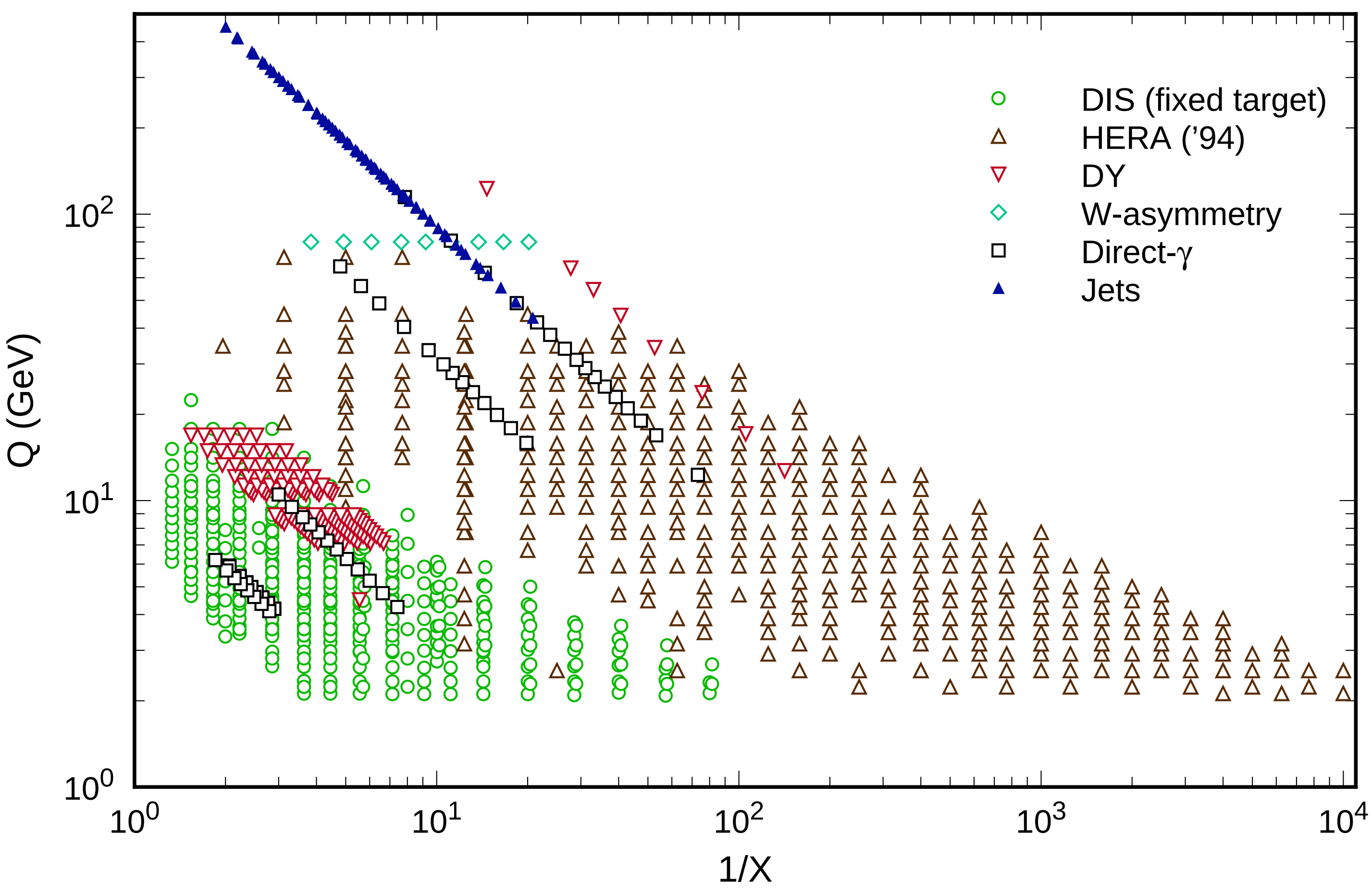

Ratio: Data / NLO QCD (CTEQ5M | CTEQ5HJ)
D0
CTEQ5M : $\chi^2 =$ 24/24 norm. factor : 1.04
CTEQ5HJ: 25/24 1.08
Incl. Jet : $p_t^7 * d\sigma/dp_t$
Data / CTEQ5M
CTEQ5HJ / CTEQ5M
D0 data
CTEQ5HJ
CTEQ5M
Error bars: statistical only
8% < Corr. Sys. Err. < 30%
p_T


Ratio: data / NLO QCD (CTEQ5M | CTEQHJ)
CDF
CTEQ5M : norm. facor : 1.00
CTEQ5HJ: 1.04
Incl. Jet : $p_t^7 * d\sigma/dp_t$
Data / CTEQ5M
CTEQ5HJ / CTEQ5M
CDF Data
CTEQ5HJ
CTEQ5M
(Error bars: statistical only)
14% < Corr. Sys. Err. < 27%
p_T



H.Weerts, January-1999

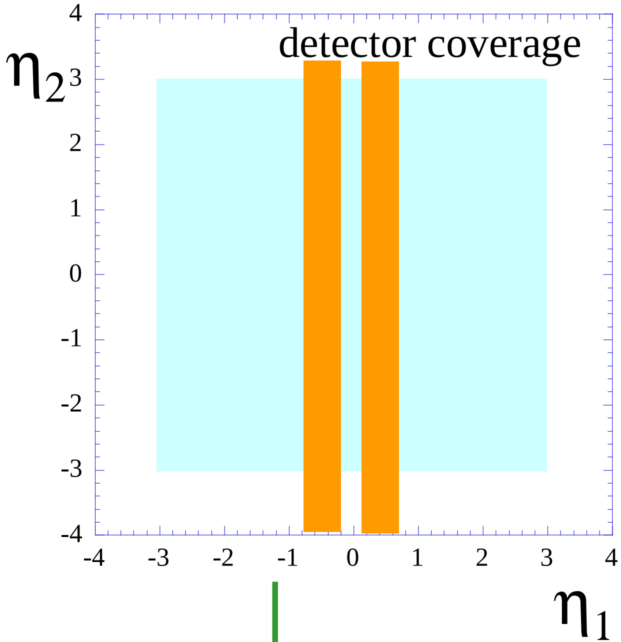
QCD/W/Z Run II workshop, H.Weerts, March 6,1999



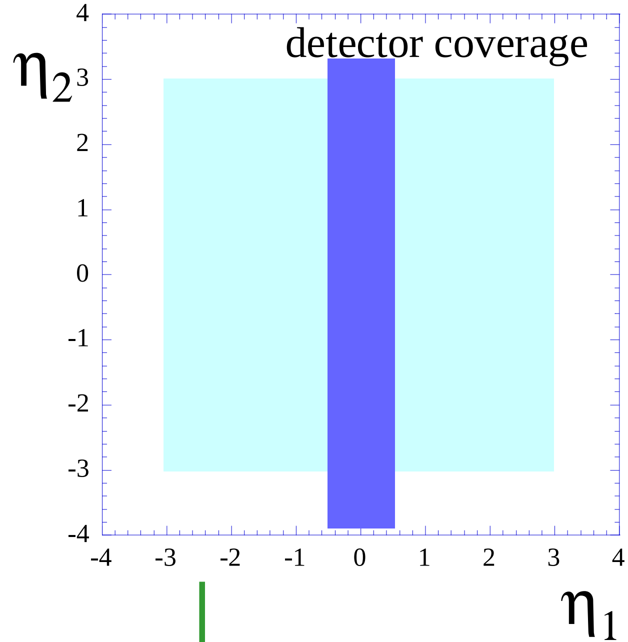
Representation of the Tevatron inclusive jet data not quite correct. Really a convolution of x_1 and x_2 , --> comes from an area in this plane.

Inclusive jet cross section in rapidity space

CDF



D0

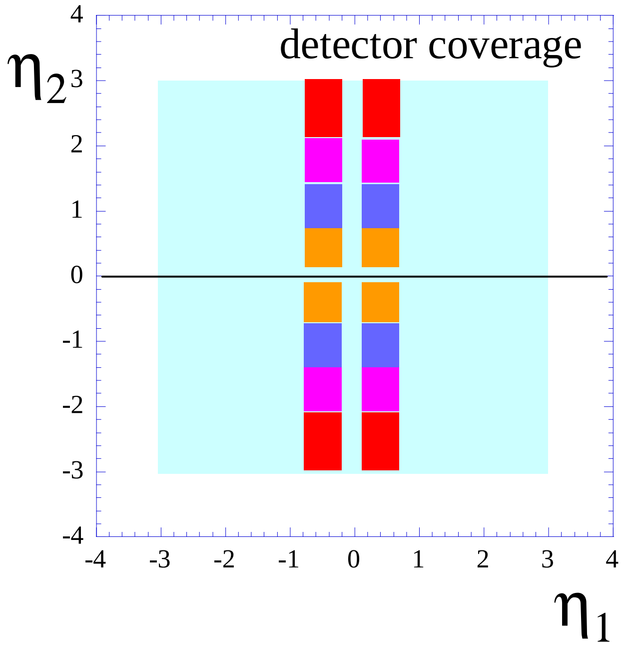


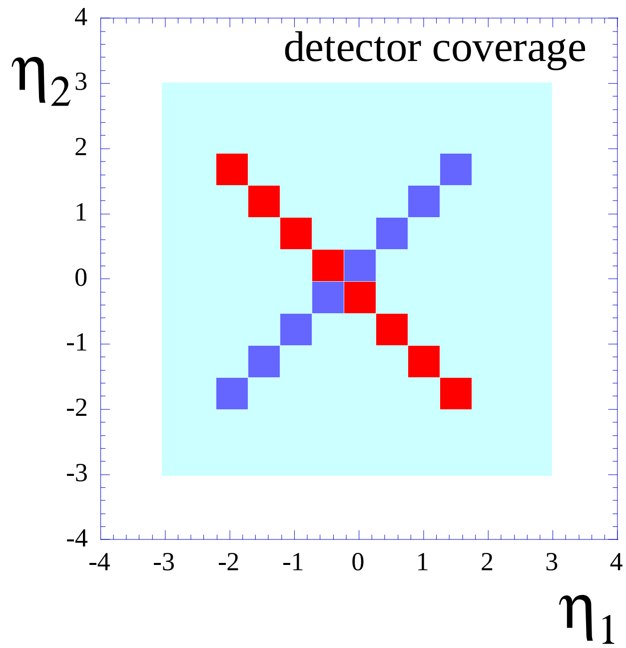
CDF

Next phase: $$\frac{d^3\sigma}{dE_T\,d\eta_1\,d\eta_2}$$

D0

Opposite side jets
Same side jets





More coverage to go,
but start.

Now in principle
can measure x_1, x_2

Using two jets in final state

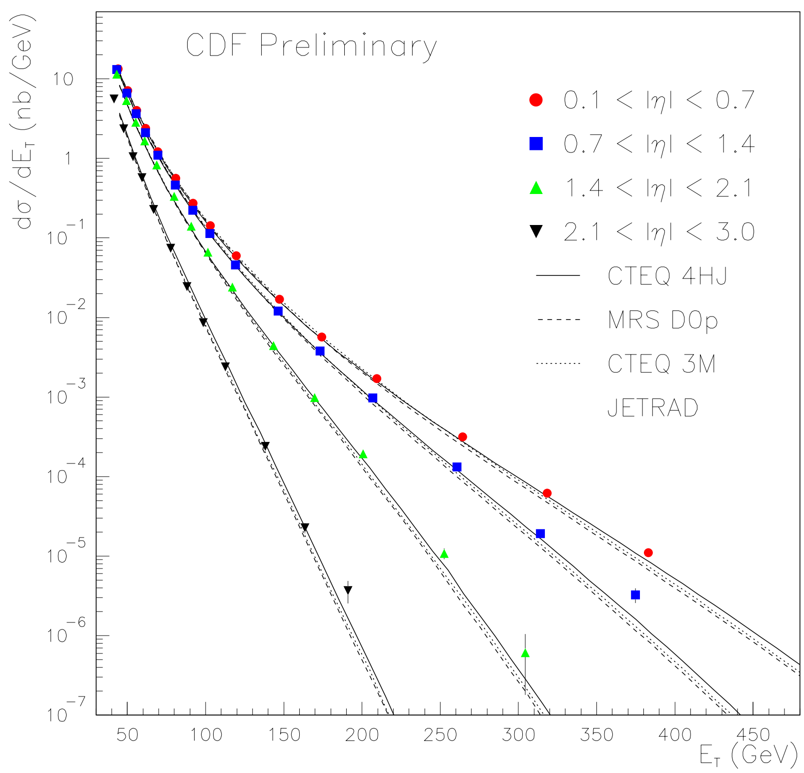
- A measurement of 2 jet final states.

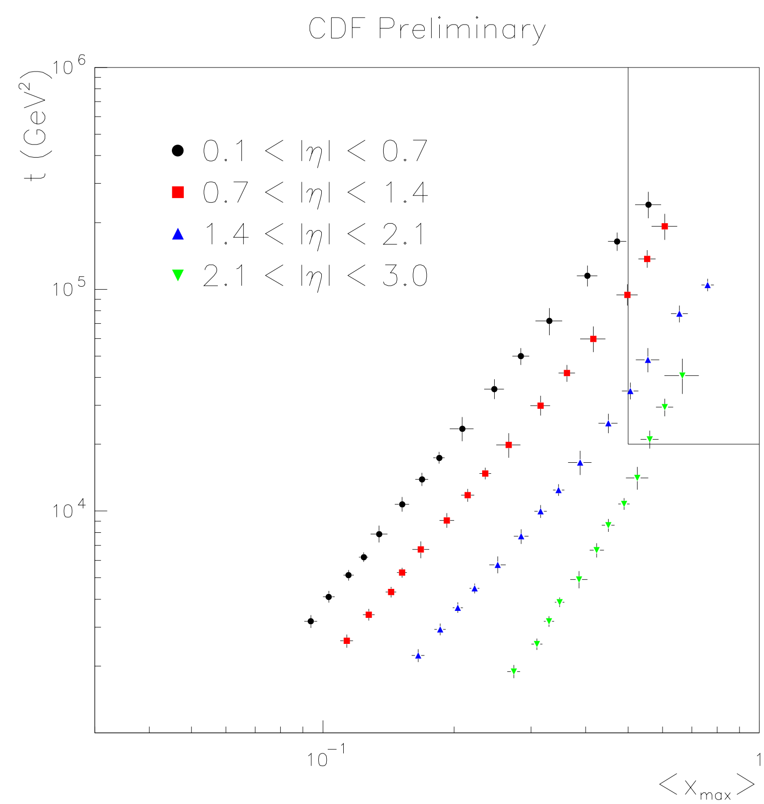
$$p + \overline{p} \rightarrow 2 \text{ jets} + \text{anything}$$

$$\frac{\partial^3 \sigma}{\partial \eta_1 \partial \eta_2 \partial E_T} \sim \sum_{i,j,k,l} x_1 f_i(x_1, Q^2)\ x_2 f_j(x_2, Q^2)\ \hat{\sigma}(i, j \rightarrow k, l)$$

- We fix the jet angles and look at E_T distributions.
- 4 pseudo-rapidity (η) bins between 0 and 2.
- Events are double counted (once for each jet).
-

= "Structure function measurement"


CDF Preliminary
0.1 < |η| < 0.7
0.7 < |η| < 1.4
1.4 < |η| < 2.1
2.1 < |η| < 3.0
CTEQ 4HJ
MRS D0p
CTEQ 3M
JETRAD
dσ/dE_T (nb/GeV)
E_T (GeV)


CDF Preliminary
0.1 < |η| < 0.7
0.7 < |η| < 1.4
1.4 < |η| < 2.1
2.1 < |η| < 3.0
t (GeV²)
< x_max >

$$p + \overline{p} \longrightarrow 2 \text{ jets} + \text{anything}$$

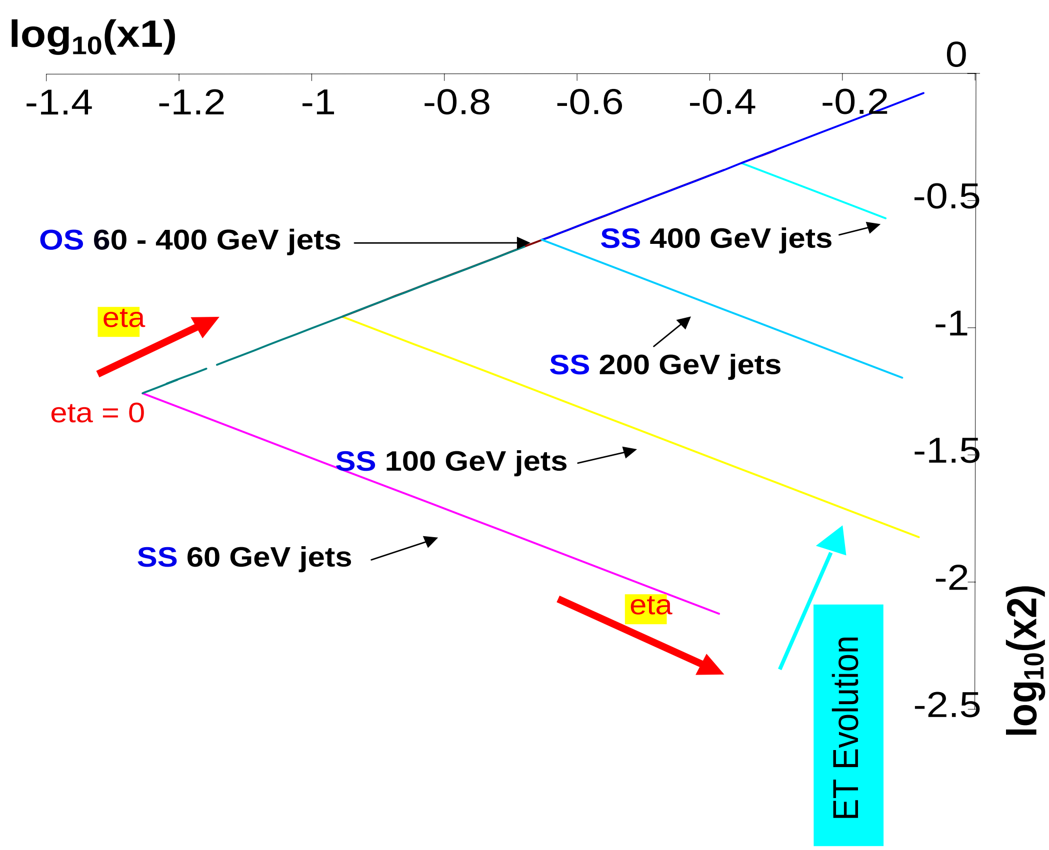
$$\frac{\partial^3 \sigma}{\partial \eta_1 \partial \eta_2 \partial E_T} \sim \sum_{i,j,k,l} x_1 f_i(x_1, Q^2) \; x_2 f_j(x_2, Q^2) \; \hat{\sigma}(i, j \rightarrow k, l)$$

•Possible to map measurement to *x* space.

$$x_{1,2} = \frac{1}{\sqrt{s}} \sum_{jets} E_{T_{jet}} e^{\pm \eta_{jet}}$$

This measurement gets down to *x* = *.01*

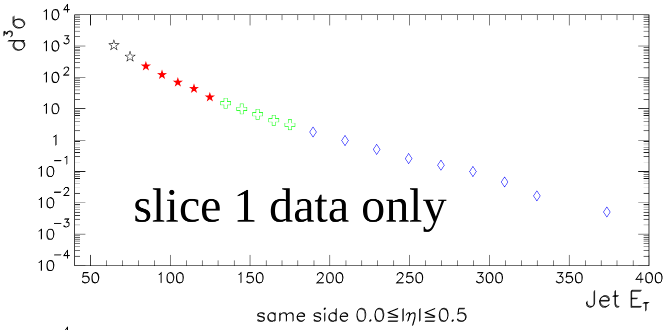
Triple Differential X Coverage

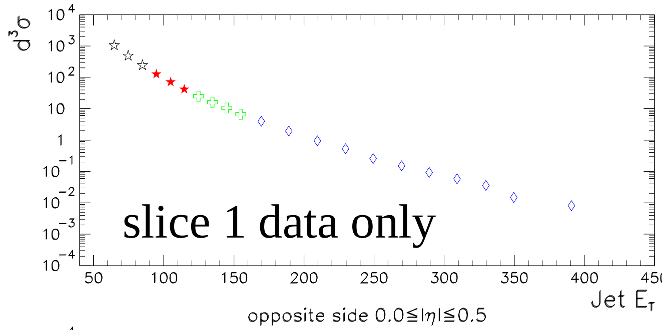


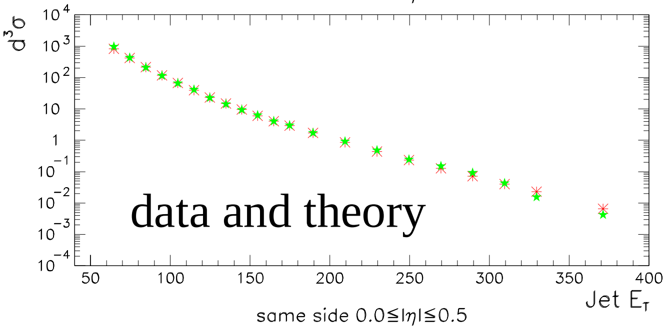
Results - Slices 1 and 2

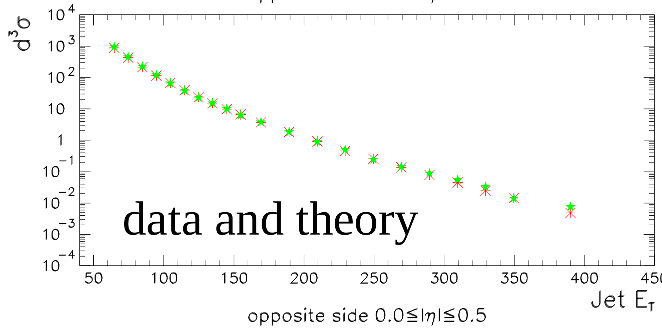
SS

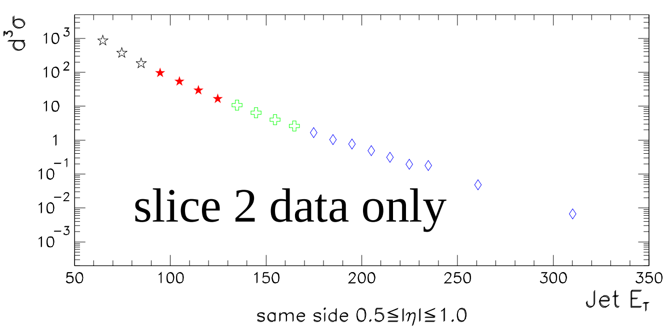
OS

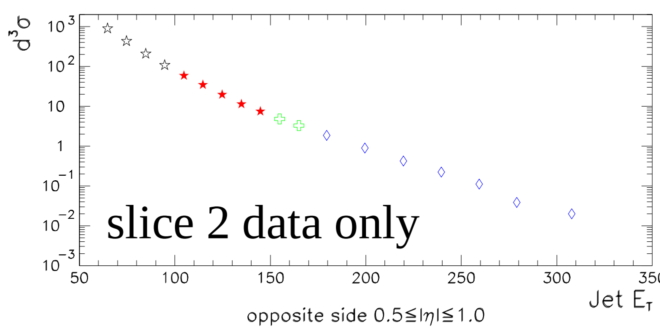


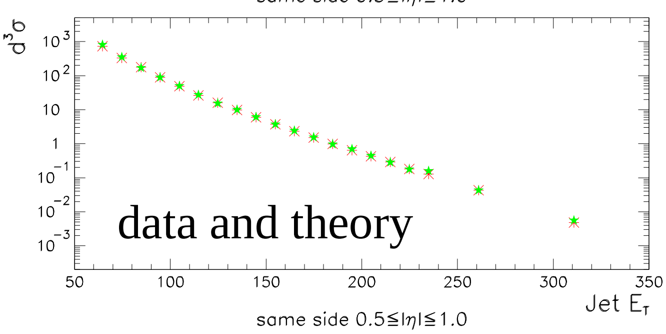


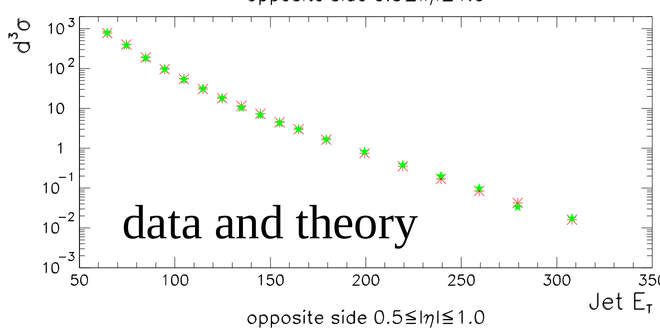










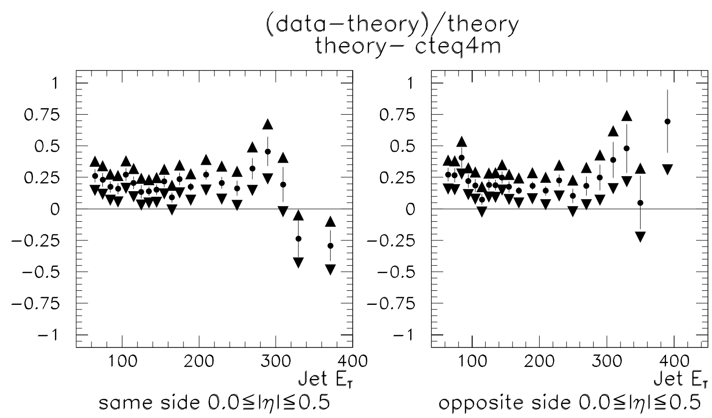


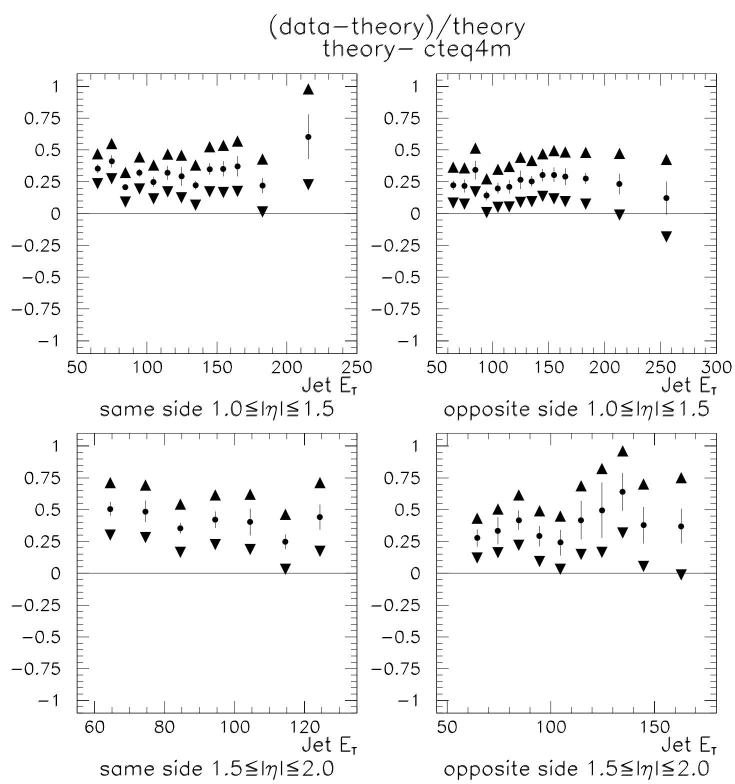
cross sections are in picobarns ~6 order of magnitude

Data Theory Comparisons continued

data compared to cteq4m

D0 triple diffential jet cross section

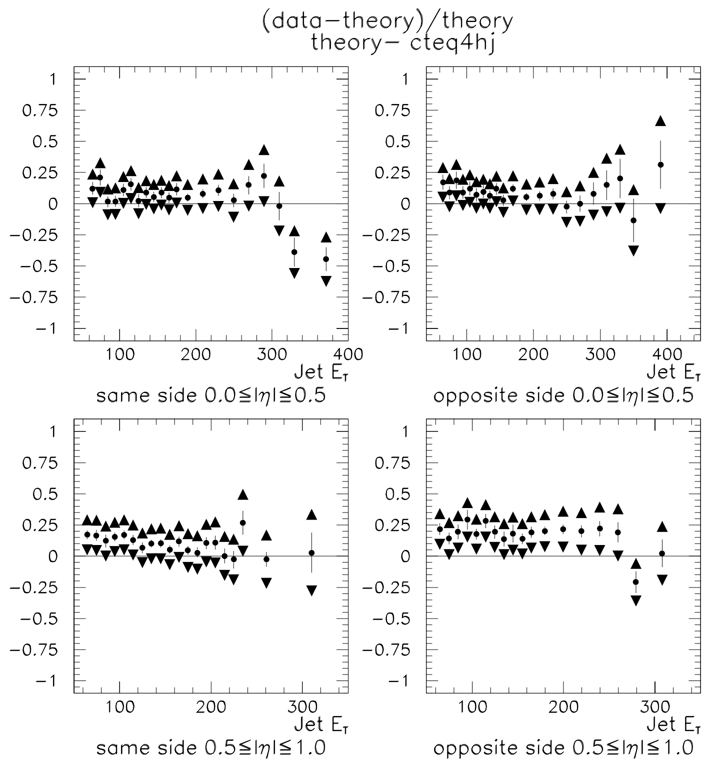


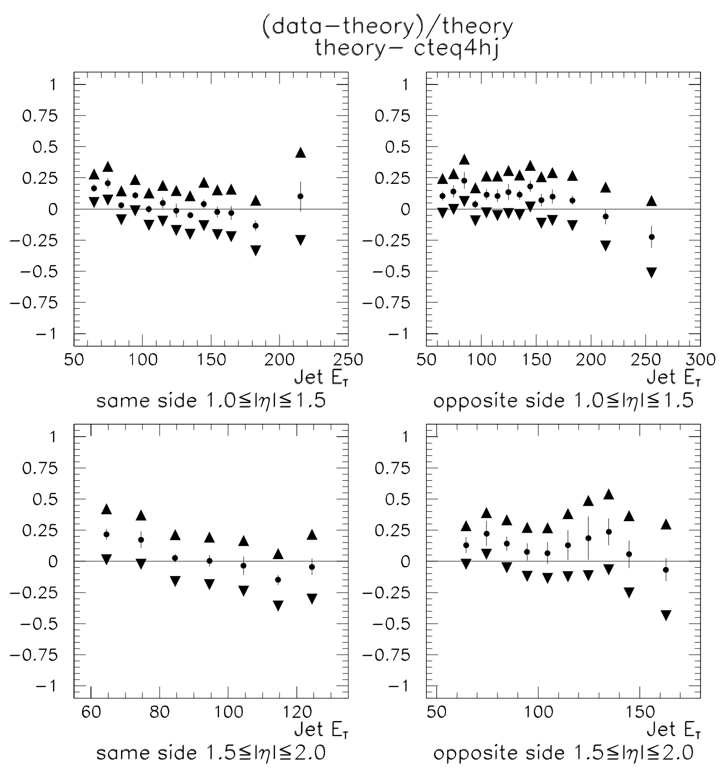


Data Theory Comparisons continued

data compared to cteq4hj

D0 triple diffential jet cross section

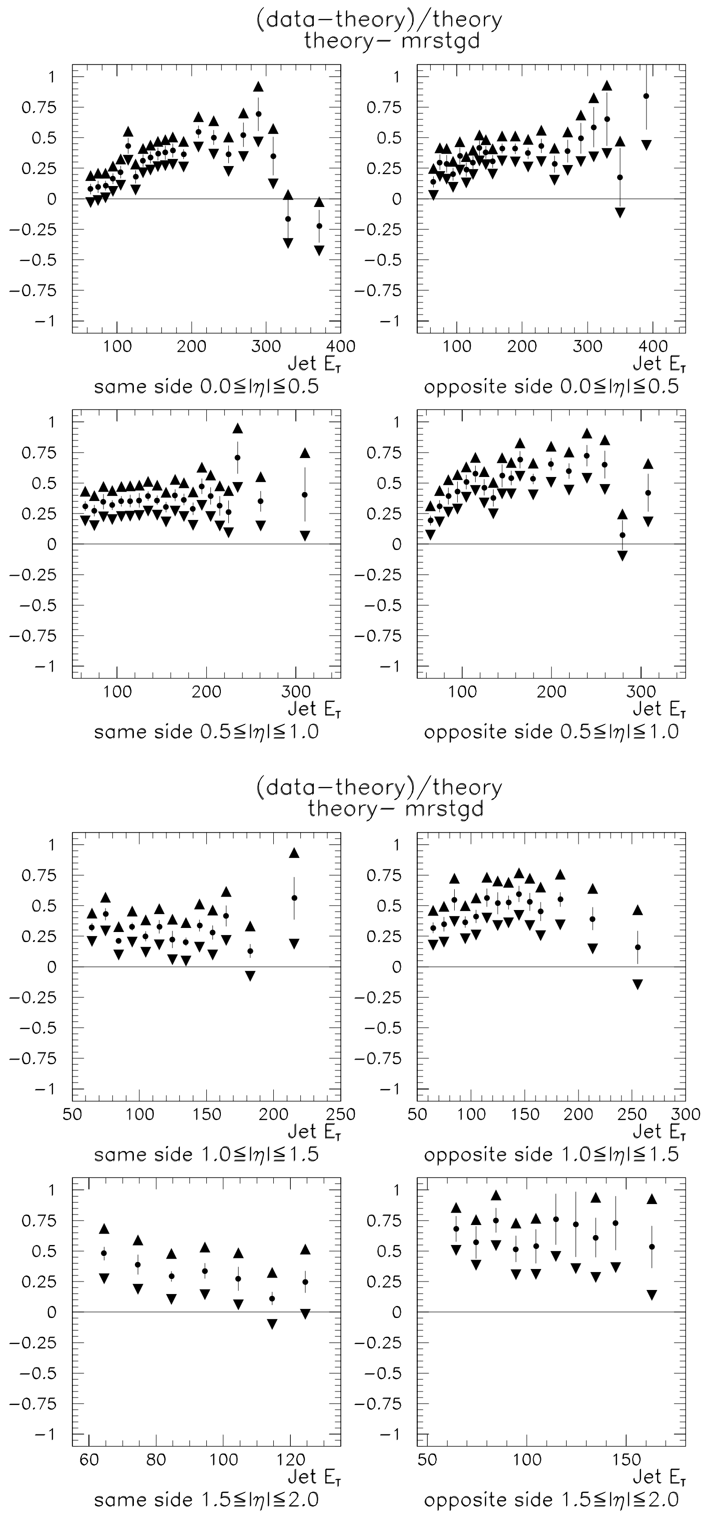




Data Theory Comparisons continued

data compared to MRSTg ↓

D0 triple diffential jet cross section



Why is this not published by D0 ???

Example of complication of jet analyses.

BFKL inspired analysis of $\sigma^{630}/\sigma^{1800}$ needs large rapidity coverage, differential cross section --> need better understanding of forward jets --> detailed study of out of cone showering in forward region (one year !) --> change out of cone correction for forward jets --> triple differential finishes one month before correction known…...

So who is to blame ?

The person who suggested the $\sigma^{630}/\sigma^{1800}$ analysis to us……..

Well known theorist and friend of D0:

Al Mueller

Of course in the end the result will be better

Jet Algorithm pains !

H.Weerts, November 1995

DØ jet definitions

"Good" old way
"DØ definition"

during clustering use:
η, ϕ a la Snowmass

$$\phi_{jet} = \frac{\sum_i E_T^i \phi^i}{\sum_i E_T^i} \; ; \; \eta_{jet} = \frac{\sum_i E_T^i \eta^i}{\sum_i E_T^i}$$

measured quantities:

$$E_x = \sum_i E_x^i; E_y = \sum_i E_y^i; E_z = \sum_i E_z^i$$
$$E = \sum_i E^i$$

$$E_T = \sum_i E_T^i$$
$$\theta_{jet} = \tan^{-1}\left(\frac{\sqrt{(\sum_i E_x^i)^2 + (\sum_i E_y^i)^2}}{\sum_i E_z^i}\right)$$
$$\phi_{jet} = \tan^{-1}\left(\frac{\sum_i E_y^i}{\sum_i E_x^i}\right)$$
$$\eta_{jet} = -\ln(\tan(\theta_{jet}/2))$$

internally **consistent**
set of variables

given $E_T, \phi_{jet}, \eta_{jet}$
can calculate E_x, E_y, E_z
and they **agree** with
measured quantities

$$E_x = E_T \cos\phi_{jet}$$
$$E_y = E_T \sin\phi_{jet}$$
$$E_z = E_T \sinh\eta_{jet}$$

The new way
Snowmass definition

during clustering use:
η, ϕ a la Snowmass

$$\phi_{jet} = \frac{\sum_i E_T^i \phi^i}{\sum_i E_T^i} \; ; \; \eta_{jet} = \frac{\sum_i E_T^i \eta^i}{\sum_i E_T^i}$$

measured quantities:

$$E_x = \sum_i E_x^i; E_y = \sum_i E_y^i; E_z = \sum_i E_z^i$$
$$E = \sum_i E^i$$

$$E_T = \sum_i E_T^i$$
$$\phi_{jet} = \frac{\sum_i E_T^i \phi^i}{\sum_i E_T^i}$$
$$\eta_{jet} = \frac{\sum_i E_T^i \eta^i}{\sum_i E_T^i}$$

inconsistent set
of variables

given $E_T, \phi_{jet}, \eta_{jet}$
can calculate E_x, E_y, E_z
and they **do not agree** with
measured quantities

$$E_x \approx E_T \cos\phi_{jet}$$
$$E_y \approx E_T \sin\phi_{jet}$$
$$E_z \neq E_T \sinh\eta_{jet}$$

Use 4-vectors

Important to establish algorithms + combination schemes now. "Impossible" to do later. Tried in D0.

W/Z + jets

Did we forget about this ?

W/Z final states will supply a real unique QCD laboratory.

Statistics will be plenty
"Clean" final state
W's and *Z*'s (*Z*'s are even better).

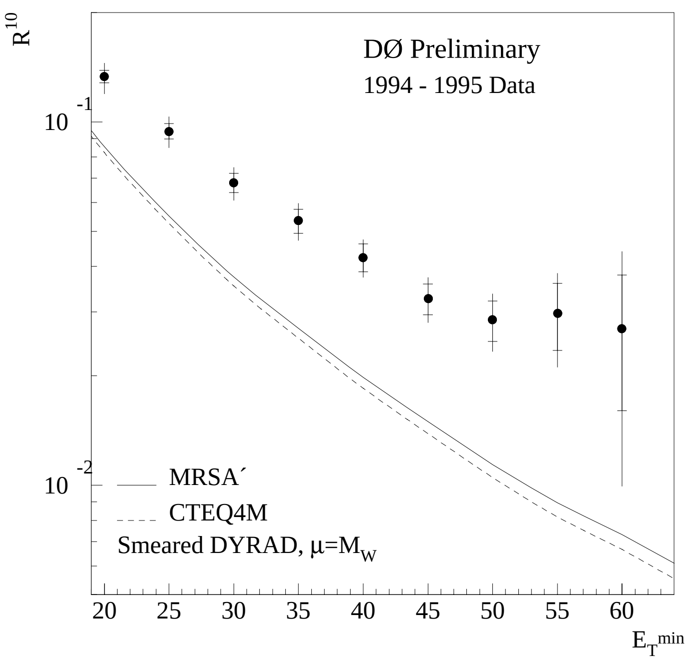
Very accurate measurement of Z $\boldsymbol{P}_t$
At low and high $\boldsymbol{P}_t$

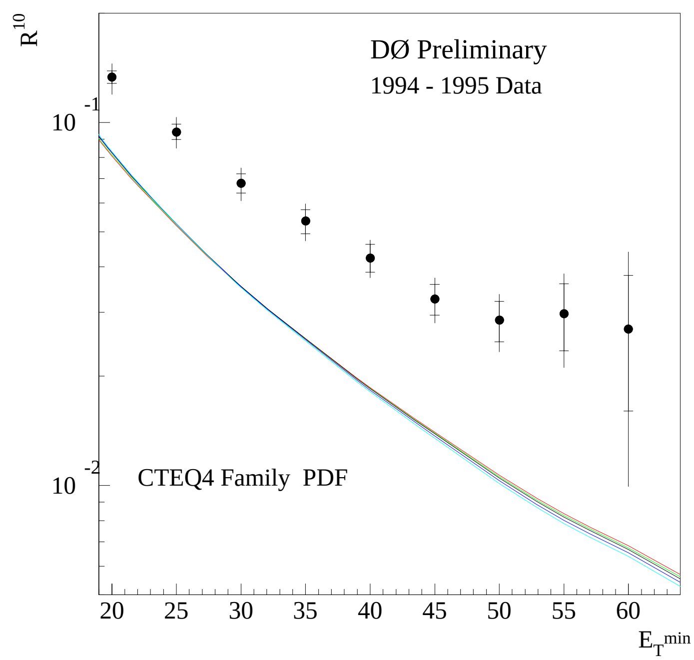
Boson + jet final states, critical to compare to predictions, push predictions

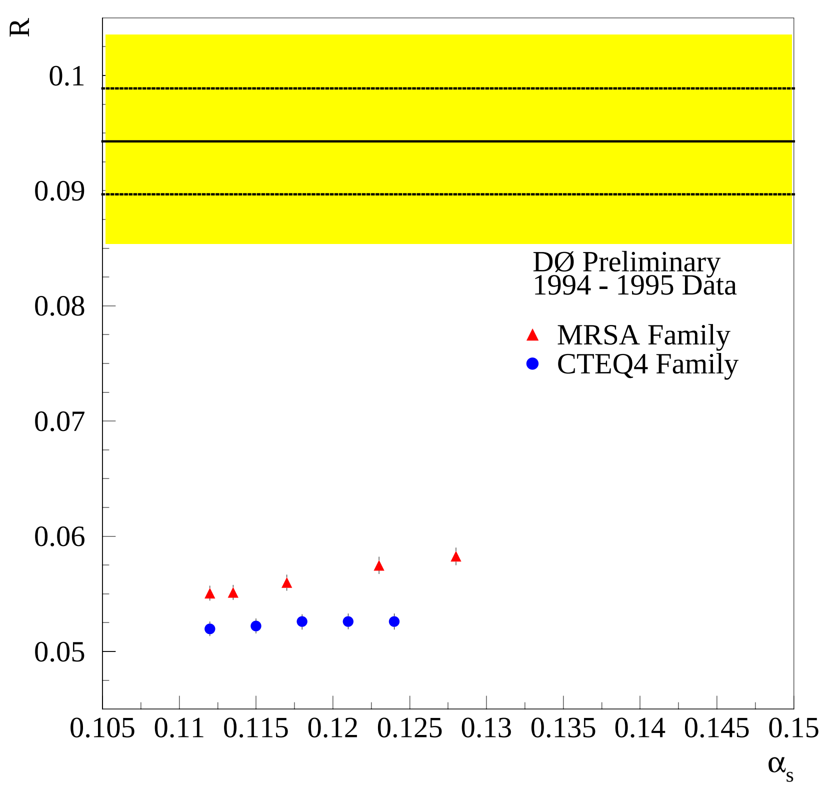
Background for many searches.

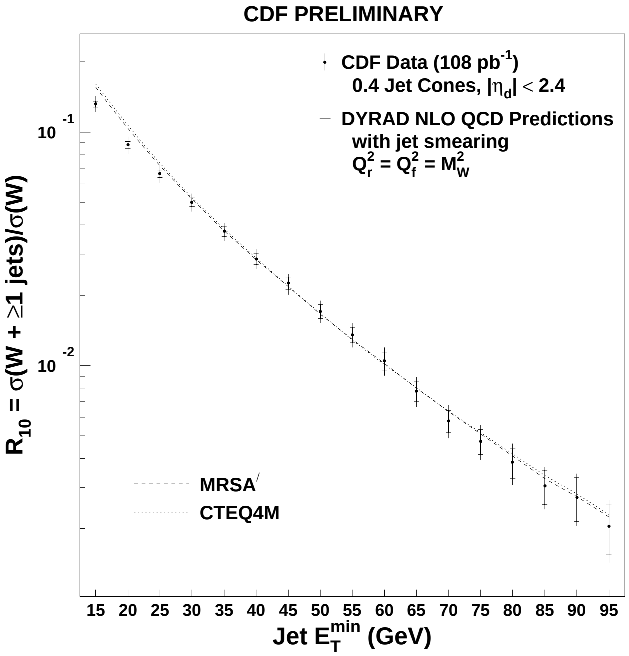
Also a painful subject…… but this is physics!

$$R^{10} = \frac{\sigma(W+1Jet)}{\sigma(W+0Jets)}$$

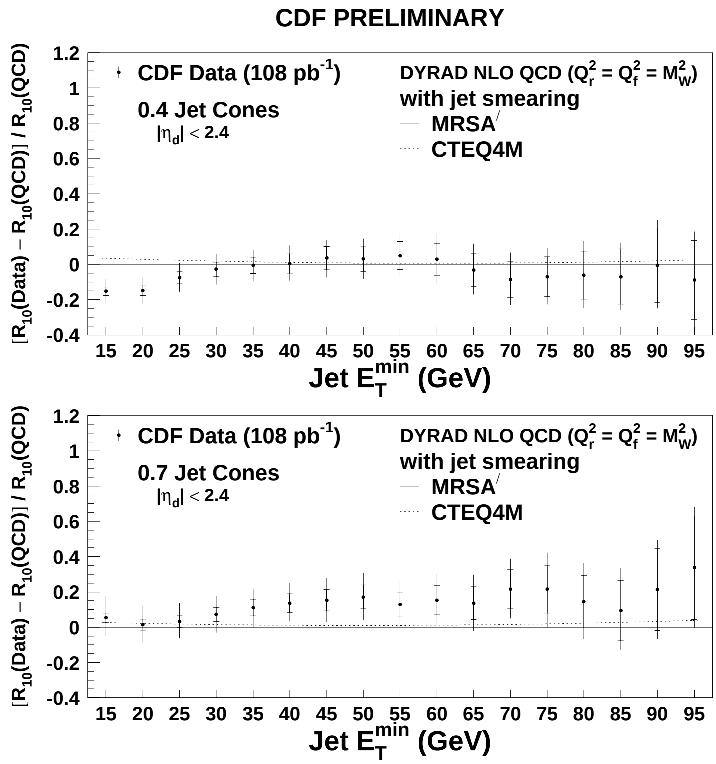


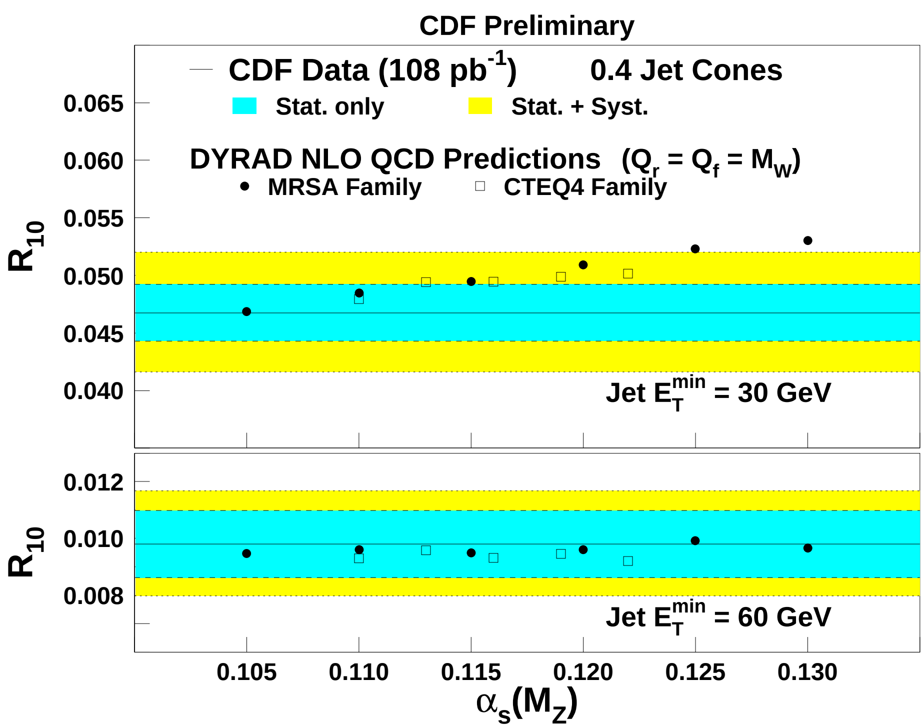






$$R^{10} = \frac{W + \geq 1\, jet}{W + \geq 0\, jet}$$





Rapidity gaps

Largest surprise in Run I (in QCD ?).

Theoretical guidance minimum, experiment driven, every result useful new information.

(HERA & Tevatron)

Very active small groups in experiments, lot of interest from theory + publications

Not taken as seriously by many others…….

Run II not just M_W, M_{top} and Higgs search

Physics potential of Tevatron huge (need to make choices)

Run II:

- both detectors improve rapidity coverage of calorimeters → even better gaps
- D0 will "have" forward proton detector

Struggle to make this happen !!

Adds to richness of Tevatron program and more quantitative "gap" physics

Luminosity !!

Not directly measured by CDF or D0.

$$Lum = \frac{N_{BBC/L0}}{\varepsilon \times accep. \times \sigma}$$

Measure !

From a simulation by CDF/D0, efficiency & acceptance

Comes from "somewhere else".

"somewhere else" determines Lum.
Not under control of experiment.

Currently depends on σ_{inelas}, σ_{elas}, $\sigma_{single\ diff.}$

σ's change: new measurements, inconsistencies etc. (*CDF*, *E710*, *E811*)

D0 change lum.

Luminosities change, measured cross sections change, confusion reigns, results become obsolete !

avoid

Quote Lum and σ in publications
--> Enable rescaling in future
results do not become obsolete

Can use any process σ^{theory}, but quote. ($\sigma_{W/Z}$)……slow.

Keep BBC/L0 counters for instantaneous luminosity monitoring (see a large cross section)

Run IB M_W Uncertainties

Error Source	$W \to e\nu$		$W \to \mu\nu$	
Statistics	65		100	
Lepton Scale	M_Z	E/p	M_Z	M_Υ
	75	80	85	20
P_T^W, Recoil Model	40		40	
PDFs	15		15	
Higher Order QED	20		10	
Lepton Resolution	25		20	
Trigger+Selection Bias	–		$15 \oplus 10$	
Backgrounds	5		25	
Total(Syst. except Scale)	54		57	
TOTAL	113	117	143	117

$$
\begin{aligned}
M_W &= 80.473 \pm 0.113 \text{ GeV (e) using } M_Z \Leftarrow \\
&= 80.055 \pm 0.117 \text{ GeV (e) using } E/p(W) \\
&= 80.465 \pm 0.143 \text{ GeV } (\mu) \text{ using } M_Z \Leftarrow \\
&= 80.441 \pm 0.117 \text{ GeV } (\mu) \text{ using } M_\Upsilon
\end{aligned}
$$

$$\boxed{M_W^{e+\mu} \text{ (Run IB)} = 80.470 \pm 0.089 \text{ GeV}}$$

Common error : 16 MeV

- DPFs : 15 MeV
- Higher order QED : 5 MeV
- P_T non-linearity : negligible
- P_T^W, Recoil Model : extracted separately between e and μ $\to$ no common error.

Wishlist

- Do event shape analysis (thrust, sphericity) in transverse plane with reconstructed objects

- Theory predictions for *b*, J/ψ production agree with data

- Have theory predictions which avoid using mixed predictions

Now use LO MC's, NLO (NNLO) predictions for cross sections and sometimes resummed predictions.
Combine !
Too confusing for experimentalists !
Also inconsistencies: $\sigma_{W/Z}$

NLO predictions with parton showers + hadronization. In one box please. Not easy, but all easy problems have been solved !

Summary

We have to complete detectors + software AND we will

BUT

Also need to be prepared for the physics -> workshops

- they should last for a few months, other work is needed
- have had successful ones already
- gives us the physics motivation for spending the $$$$, very good for SUSY/Higgs
- document the physics motivation, go from hand waving approximations to careful simulations
- interaction theory-experiment
- interaction experiment-experiment (!!)
- more fun to build detector when physics case is well made and documented
- documentation very important for future students & postdocs
- both CDF & D0 support having these workshops
- delay in detectors small compared to technical problems (not everybody will agree)

Hope enthusiastic workshop startup will continue and result in a final written document.

Workshops like this crucial to the Tevatron program for Run II